Fermi National Accelerator Laboratory

FERMILAB-Conf-97/249-E
CDF

Physics of the Top Quark at CDF

Steve Vejcik
For the CDF Collaboration
University of Michigan

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

July 1997

Published Proceedings of the *11th Les Rencontres de Physique de la Vallee d'Aoste: Results and Perspectives in Particle Physics*, La Thuile, Italy, March 2-8, 1997

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CH03000 with the United States Department of Energy

CDF/PUB/CDF/PUBLIC/4243

Physics of the Top Quark at CDF

Proceedings for Les Rencontres de Physique de la Vallee d'Aoste
(La Thuile, March 2-8 1997)

Steve Vejcik for the CDF Collaboration

University of Michigan

Abstract

Measurements of Top quark properties with the CDF detector are reported. The production cross section and mass provide a consistent picture of the Top quark as described by the Standard Model. Initial studies of other properties such as estimates of branching ratios are also reported.

1 Introduction

The Top quark is defined as the weak isospin partner of the b-quark. Its discovery [1] completes the multiplet structure of fermions within the Standard Model and cements the expectations of that theory. Beyond establishing its existence, an experimental program designed to measure its properties can expand the understanding of the Electroweak sector and possibly yield unexpected features. The relevant studies performed at CDF are the measurements of the production cross section ($\sigma_{t\bar{t}}$) and mass (M_{top}) and the examination of top production and decay features such as branching ratios, the $t\bar{t}$ invariant mass ($M_{t\bar{t}}$), and evidence of unexpected or rare decay channels. Additional attention has also been given to understanding what such studies could yield with higher luminosity samples expected in the future.

The measurments reported here reflect preliminary results from the CDF experiment and are based on recorded luminosities of $109pb^{-1}$ obtained at the Fermilab Tevatron. CDF is a general purpose detector designed to detect and measure properties of jets and leptons, missing energy, and identify displaced secondary vertices with a silicon vertex detector. Each of these elements is important for the reconstruction of $t\bar{t}$ events. The expected decay of $t\bar{t}$ pairs results in a final state of a b- and a $\bar{b}$-jet and two on-shell W bosons. The subsequent decay of the W bosons classifies the decay as either *dilepton* (both W's decaying to $e\nu$ or $\mu\nu$), *lepton+jet* (one leptonic W decay and one hadronic decay), or *hadronic* (both W's decaying hadronically). The selection of top candidates relies on identifiying events passing a series of cuts corresponding to the relevant topology. Dilepton candidates, for instance, are required to contain two isolated lepton candidates, large missing transverse energy ($\not{E}_T$), and at least two jets. 10 such events are identified as candidate events by CDF with little (2 events expected) accompanying background. Additional background rejection is needed in other decay channels and can be obtained by requiring evidence of b-quark production among the observed jets. Identification of b-jets proceeds either by identifying displaced secondary vertices, expected from long lived b-hadron decays, or by the observation of extra leptons signaling the presence of semileptonic b-hadron decays. The respective efficiencies of the two algorithms are approximately 42% and 20%.

2 Measurements of the Production Cross Section

The combined branching fraction times efficiency for the different channels varies from approximately a tenth of a percent to almost 5%. Table 1 shows the measured cross sections for the different observed channels. The most precise determination of the cross section is arrived at through the combination of the measurements in the dilepton and two lepton+jet channels, yielding a measurement of $\sigma_{t\bar{t}} = 7.5^{+1.9}_{-1.7}pb$. For a top mass of 175 GeV/c^2, the measured cross section is slightly more than one standard deviation from typical predictions of $\sim$ 5pb [2].

Table 1: Measured $t\bar{t}$ production cross sections from CDF.

Channel	Acceptance $\times$ BR(%)	Background	N_{obs}	$\sigma_{t\bar{t}}(pb)$
Dilepton	0.74 ± 0.08	2.1 ± 0.4	9	$8.5^{+4.4}_{-3.4}$
Lepton+Jets (SVX Tagged)	3.5 ± 0.7	8.0 ± 1.4	34	$6.8^{+2.3}_{-1.8}$
Lepton+Jets (SLT Tagged)	1.7 ± 0.3	24.3 ± 3.5	40	$8.0^{+4.4}_{-3.6}$
All Hadronic	4.7 ± 1.6	137.1 ± 11.3	192	$10.7^{+7.6}_{-4.0}$
τ-Dilepton	0.119 ± 0.014	1.96 ± 0.35	4	$15.6^{+18.6*}_{-13.2}$
b-tagged Dilepton	0.51 ± 0.03	1.4 ± 0.3	4	$4.6^{+4.4}_{-3.1}$
Combined Lepton+Jets (SVX and SLT) and Dilepton				$\mathbf{7.5^{+1.9}_{-1.6}}$

* Statistical Only

3 Measurement of the Top Quark Mass

The measurement of the Top quark mass is achievable for $t\bar{t}$ events decaying in dilepton, fully hadronic, or lepton+jet decay channels. The most precise measurement is presently achieved through the complete reconstruction of events in the lepton+jets channel. Such a technique is based on the measurements of jets and leptons in events combined with the kinematic constraints implied by two on-shell W-bosons and a single common mass for the two top quarks in each event. The simultaneous constraint to the kinematics and measurements yields an estimated top quark mass for individual events. The resolution for individual events is dominated by the ambiguity in the assignment of partons to jets and by events with additional jets due to final and initial state radiation. These two effects increase the intrinsic resolution of $\sim$ 13GeV/c^2 to $\sim$ 30 GeV/c^2.

Figure 1 shows the distribution obtained from the data separated into different categories based on tagging information. The measured mass is arrived at by comparing the distribution of masses for each tagging category with Monte Carlo models varying by Top mass. The inset plot of Figure 1 shows the simultaneous comparison for all channels to different top masses obtained with a maximum likelihood analysis. The minimum of the corresponding parabolic fit to this comparison yields the Top mass of 176.8 ± 4.4 GeV/c^2.

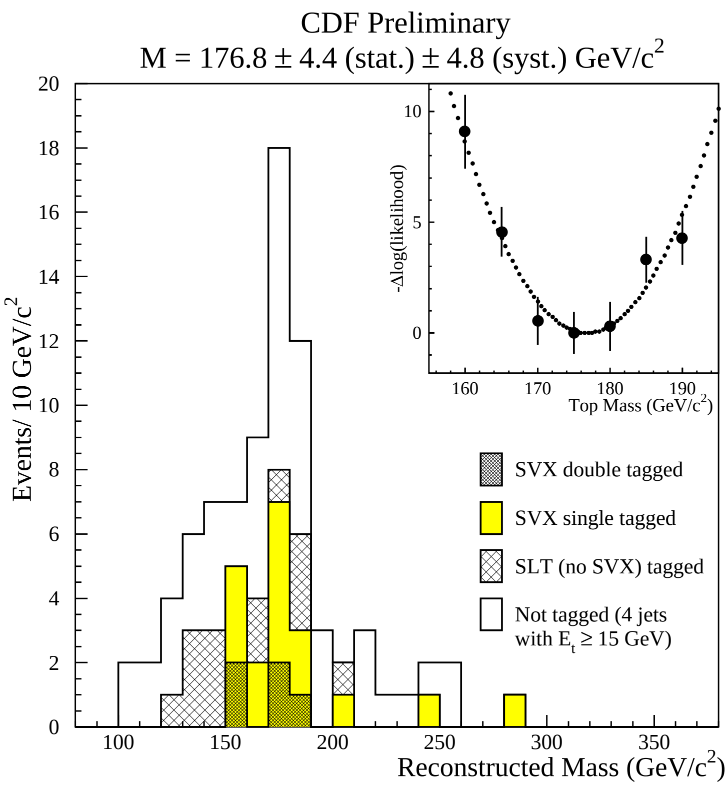

Figure 1: Reconstructed mass distributions for candidate $t\bar{t}$ events decaying through the lepton+jets channel. The inset plot represents the comparison of the distributions with those expected from $t\bar{t}$ events with different masses. The minimum of the subsequent parabolic fit indicates the estimated value of M_{top}.

The most important systematic uncertainties in the measured mass are due to the uncertainties in the jet E_T scale and in the modeling of effects due to hard gluons such as those present in final state radiation. The respective uncertainties in M_{top} from these effects are 2% and 1.3%. The total systematic uncertainty in M_{top} is estimated to be 2.5%. Future measurements of M_{top} at either the Tevatron or LHC are expected to be dominated by similar systematic effects. If controllable to the level of 1%, a measurement of M_{top} with a 2 GeV/c^2 precision may be achievable in these venues.

The measurement of M_{top} has also been achieved with candidate top events identified in the fully hadronic channel. This measurement relies on a constrained fit similar to that used for lepton+jet events and results in $M_{top} = 186 \pm 10 \pm 12$ GeV/c^2.

4 Searches for Anomolous Decay or Production Properties

The study of candidate $t\bar{t}$ events allows assumptions about their production and decays to be tested. The conventional decay of one top quark provides a trigger for a relatively unbiassed sample of decays of its partner antiquark. The resulting event sample can then be searched for unexpected or suppressed decay channels which could provide the first indications of non-Standard Model physics. One possibility is the decay $t \to (\gamma, Z^0)c$. Such events would have a signature of a single well identified W-boson, jets, and an accompanying photon or Z^0. The identification of a single candidate, consistent with known background rates, yields 95% confidence limits on the respective top branching ratios for the γ and Z^0 channels of 90% and 2.9%.

Other studies include using the reconstructed $t\bar{t}$ mass spectrum to search for resonant $t\bar{t}$ production, the non-b-tagged dijet mass spectrum to search for evidence of top decays unaccompanied by a W-boson, and the b-tag multiplicity distribution to measure the branching ratio of $B \equiv \Gamma(t \to Wb)/\Gamma(t \to Wq)$. The analysis of both dilepton and lepton+jet events with 4 or more jets provides a lower limit of $B > 0.58$ at 95% confidence interval. The result can be recast as a limit on the CKM matrix element $V_{tb} > 0.76$ at 95% confidence limit, assuming unitarity. The picture that emerges from the collective set of studies indicates no evidence of anomolous (non-Standard Model) behavior within candidate $t\bar{t}$ events.

5 Conclusion

The discovery of the Top quark represents the achievement of a central goal for the Tevatron collider program and cements the validity of the Standard Model description of the low energy electroweak picture having the multiplet structure expected of a spontaneously broken SU(2)xU(1) gauge theory. The experimental program has subsequently focused on the measurement of production and decay properties. The production rate measured through its cross section ($\sigma_{t\bar{t}} = 7.5^{+1.9}_{-1.6}\ pb$) is consistent with that predicted by QCD. The full reconstruction of $t\bar{t}$ events yields a measured value of $M_{top} = 176.8 \pm 4.4 \pm 4.8$ GeV/c^2. No evidence for either anomolous decays or production have been observed.

References

[1] F. Abe et al., Phys. Rev. Lett.**73**,225 (1994); F. Abe et al.,Phys. Rev. Lett. **74** 2626

(1995); S. Abachi et al., Phys. Rev. Lett. **74**, 2632 (1995).

[2] E. Berger & H. Contopanagos, Phys. Rev. **D54**, 3085 (1996); S. Catani, M.L. Mangano, P. Nason, & L. Trentadue, Phys. Lett. **B378**, 329 (1996); E. Laenen, J. Smith, & W.L. Van Neerven, Phys. Lett. B**321**,254 (1994).